NEW RESULTS FROM THE NEMO 3 EXPERIMENT

V.I. TRETYAK on behalf of the NEMO Collaboration
Institute Pluridisciplinaire Hubert Curien,
23 Rue du Loess, BP 28, 67037 Strasbourg, France
on leave of absence from Joint Institute for Nuclear Research,
Joliot Curie 6, 41980 Dubna, Russia

NEMO 3 is a currently running experiment to search for the neutrinoless double beta decay and to study the two-neutrino double beta decay with 10kg of enriched isotopes. On the basis of the first two years of data taking, a limit on the neutrinoless decay $T^{0\nu}_{1/2} > 5.8 \cdot 10^{23}$ y at 90% CL was obtained with ^{100}Mo. The two-neutrino double beta decay half-lives were measured for all seven $\beta\beta$ isotopes located in NEMO 3. New results are obtained for two of these isotopes: $^{48}Ca\ T^{2\nu}_{1/2} = [4.4^{+0.5}_{-0.4}(stat) \pm 0.4(syst)] \cdot 10^{19} y$, $^{96}Zr\ T^{2\nu}_{1/2} = [2.3 \pm 0.2(stat) \pm 0.3(syst)] \cdot 10^{19} y$.

1 Introduction

Experimental search for the neutrinoless double beta decay ($0\nu\beta\beta$) is of a major importance in particle physics because if observed, it will reveal the Majorana nature of the neutrino ($\nu \equiv \bar{\nu}$) and may allow an access to the absolute neutrino mass scale. The $0\nu\beta\beta$-decay violates the lepton number and is therefore a direct probe for the physics beyond the standard model. A possibility of this process may be related to right-handed currents in electroweak interactions, supersymmetric particles with R-parity nonconservation, massless Goldstone bosons such as majorons. In the case of the neutrino-mass mechanism the $0\nu\beta\beta$ decay rate can be written as

$$[T^{0\nu}_{1/2}(A,Z)]^{-1} = \langle m_\nu \rangle^2 \cdot |M^{0\nu}(A,Z)|^2 \cdot G^{0\nu}(Q_{\beta\beta}, Z), \qquad (1)$$

where $\langle m_\nu \rangle$ is the effective neutrino mass, $M^{0\nu}$ is the nuclear matrix element (NME), and $G^{0\nu}$ is the kinematical factor proportional to the transition energy to the fifth power, $Q^5_{\beta\beta}$.

The spontaneous two-neutrino double beta decay ($2\nu\beta\beta$) is a rare second-order weak interaction process. The accurate measurement of the $2\nu\beta\beta$-decay is important since it constitutes the ultimate background in the search for 0ν-decay signal. It is useful for the test of the nuclear structure and provides valuable input for the theoretical calculations of the $0\nu\beta\beta$-decay NME.

The objective of the NEMO 3 experiment is the search for the $0\nu\beta\beta$-decay and investigation of the $2\nu\beta\beta$-decay with 10 kg of $\beta\beta$ isotopes.

2 NEMO 3 experiment

2.1 The NEMO 3 detector

The NEMO 3 has been taking data since 2003 in the Modane underground laboratory located in the Frejus tunnel at the depth of 4800 m w.e. Its method of $\beta\beta$-decay study is based on the detection of the electron tracks in a tracking device and the energy measurement in a calorimeter.

The detector [1] has a cylindrical shape. Thin source foils ($\sim 50\ mg/cm^2$) are located in the middle of the tracking volume surrounded by the calorimeter. Almost 10kg of enriched $\beta\beta$ isotopes (listed in Table 1) were used to produce the source foils. The tracking chamber contains 6180 open drift cells operating in the Geiger mode. It provides a vertex resolution of about 1 cm. The calorimeter consists of 1940 plastic scintillator blocks with photomultiplier readout. The energy resolution is 14-17%/$\sqrt{E}$ FWHM. The time resolution of 250 ps allows excellect suppression of the crossing electron background. A 25 G magnetic field is used for charge identification. The detector is capable of identifying e^-, e^+, γ and α particles and allows good discrimination between signal and background events.

2.2 Event selection and background model

The $\beta\beta$ events are selected by requiring two reconstructed electron tracks with a curvature corresponding to the negative charge, originating from a common vertex in the source foil. The energy of each electron measured in the calorimeter should be higher than 200 keV. Each track must hit a separate scintillator block. No extra PMT signal is allowed. The event is recognized as internal by using the measured time difference of two PMT signals compared to the estimated time of flight difference of the electrons.

The background can be classified in three groups: external one from incoming γ, radon inside the tracking volume and internal radioactive contamination of the source. All three were estimated from the NEMO 3 data with events of various topologies. In particular, radon and internal ^{214}Bi were measured with $e\gamma\alpha$ events. The $e\gamma$, $e\gamma\gamma$, and $e\gamma\gamma\gamma$ events are used to measure the ^{208}Tl activity requiring the detection of the 2.615 MeV γ-ray typical of the ^{208}Tl β-decay. Single electron events are used to measure the foil contamination by β-emitters. The external background is measured with the events with the detected incoming γ-ray producing an electron in the source foil. The external background is checked with two-electron events originating from pure copper and natural tellurium foils. Measurements performed with an HPGe detector and radon detectors are used to verify the results.

3 NEMO 3 results

3.1 Measurement of $2\nu\beta\beta$ half-lives

Measurements of the $2\nu\beta\beta$ decay half-lives were performed for 7 isotopes available in NEMO 3 (see Table 1). New preliminary results based on higher statistics than previously are presented here for two of these isotopes: ^{48}Ca and ^{96}Zr.

Table 1: NEMO 3 results of half-life measurement.

Isotope	Mass (g)	$Q_{\beta\beta}$ (keV)	Signal/Background	$T_{1/2}$ [10^{19} years]
^{100}Mo	6914	3034	40	0.711 ± 0.002 (stat) ± 0.054 (syst) [2]
^{82}Se	932	2995	4	9.6 ± 0.3 (stat) ± 1.0 (syst) [2]
^{116}Cd	405	2805	7.5	2.8 ± 0.1 (stat) ± 0.3 (syst)
^{150}Nd	37.0	3367	2.8	$0.920^{+0.025}_{-0.022}$(stat) ± 0.062 (syst)
^{96}Zr	9.4	3350	1.	2.3 ± 0.2 (stat) ± 0.3 (syst)
^{48}Ca	7.0	4772	6.8	$4.4^{+0.5}_{-0.4}$(stat) ± 0.4 (syst)
^{130}Te	454	2529	0.25	76 ± 15 (stat) ± 8 (syst)

The measurement of the ^{96}Zr half-life was performed using the data collected within 925 days. A total of 678 events were selected, with the expected 328 background events. The

largest background contribution is due to the internal ^{40}K contamination of the sample. The distribution of the energy sum of two electrons and their angular distribution are shown in Fig. 1, demonstrating good agreement of the data with the Monte Carlo simulation. The $2\nu\beta\beta$ efficiency is estimated to be 7.6%. The measured half-life is $T^{2\nu}_{1/2}(^{96}Zr) = [2.3 \pm 0.2(stat) \pm 0.3(syst)] \cdot 10^{19} y$.

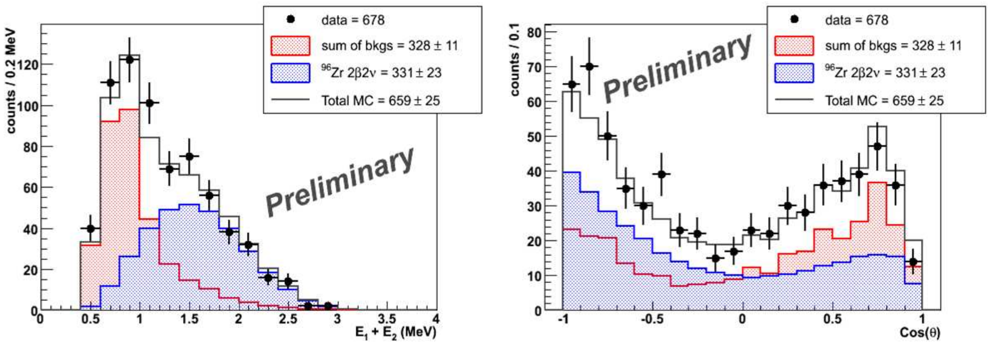

Figure 1: The energy sum and angular distributions for two-electron events from ^{96}Zr.

The ^{48}Ca sample used in NEMO 3 is known to be contaminated by ^{90}Sr(T$_{1/2}$=28.79 y, Q_β=0.546 MeV). Its daughter ^{90}Y (T$_{1/2}$=3.19 h, Q_β=2.282 MeV) is the major background source in this case. An activity of 1699 ± 3 mBq/kg was measured for ^{90}Y using single-electron events. Both ^{90}Sr and ^{90}Y are essentially pure β^- emitters and imitate $\beta\beta$ events through Möller scattering. To supress this background contribution, events with the energy sum greater than 1.5 MeV and $cos(\Theta_{ee}) < 0$ are selected. Finally, with 943 days of data taking, there are a total of 133 two-electron events, with an evaluated residual background contribution of 17 events. Their two-electron energy sum distribution and single-electron energy spectrum are presented in Fig. 2. The $2\nu\beta\beta$ efficiency is 3.3%, and the measured half-life is $T^{2\nu}_{1/2}(^{48}Ca) = [4.4^{+0.5}_{-0.4}(stat) \pm 0.4(syst)] \cdot 10^{19} y$.

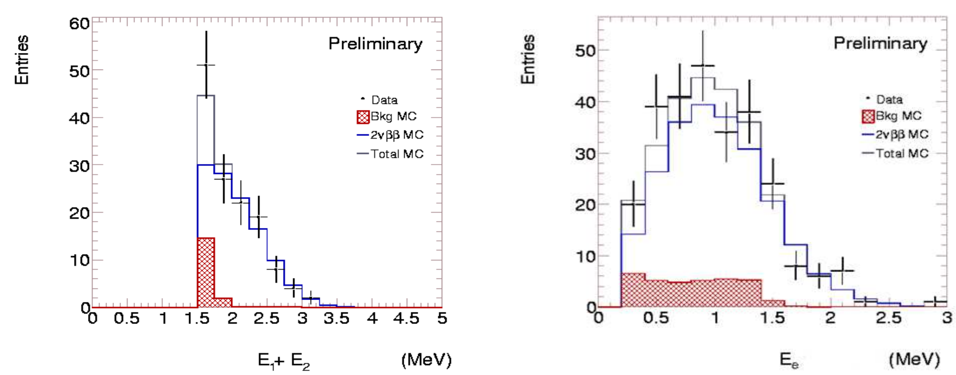

Figure 2: The energy sum and single-electron energy spectra for two-electron events from ^{48}Ca.

3.2 Search for $0\nu\beta\beta$ decay

In the case of the mass mechanism, the $0\nu\beta\beta$-decay signal is expected to be a peak in the energy sum distribution at the position of the transition energy $Q_{\beta\beta}$. Since no excess is observed at the tail of the distribution for ^{96}Zr, see Fig. 1 (left), nor for ^{48}Ca, Fig. 2 (left), limits are set

on the neutrinoless double beta decay $T^{0\nu}_{1/2}$ using the CLs method [3]. A lower half-life limit is translated into an upper limit on the effective Majorana neutrino mass $\langle m_\nu \rangle$ (see Eq. 1). The following results are obtained using the NME values from [4, 5] for ^{96}Zr and from [6] for ^{48}Ca

$T^{0\nu}_{1/2}(^{96}Zr) > 8.6 \cdot 10^{21} y$ (90% C.L.) $\quad \langle m_\nu \rangle < 7.4 - 20.1$ eV

$T^{0\nu}_{1/2}(^{48}Ca) > 1.3 \cdot 10^{22} y$ (90% C.L.) $\quad \langle m_\nu \rangle < 29.7$ eV.

The $0\nu\beta\beta$-decay search in NEMO 3 is most promising with ^{100}Mo and ^{82}Se because of the larger available isotope mass and high enough $Q_{\beta\beta} \sim 3$ MeV. The two-electron energy sum spectra obtained from the analysis of the data taken within 693 days are shown in Fig. 3. For ^{100}Mo there are 14 events observed in the 0ν search window [2.78-3.20] MeV in good agreement with the expected background of 13.4 events. For ^{82}Se there are 7 events found in the energy sum interval [2.62-3.20] MeV, compared to the expected background of 6.4 events. The limits on the $T^{0\nu}_{1/2}$ and the corresponding $\langle m_\nu \rangle$ limits calculated using the recent NME values [4, 5] are

$T^{0\nu}_{1/2}(^{100}Mo) > 5.8 \cdot 10^{23} y$ (90% C.L.) $\quad \langle m_\nu \rangle < 0.61$–$1.26$ eV

$T^{0\nu}_{1/2}(^{82}Se) > 2.1 \cdot 10^{23} y$ (90% C.L.) $\quad \langle m_\nu \rangle < 1.4 - 2.2$ eV.

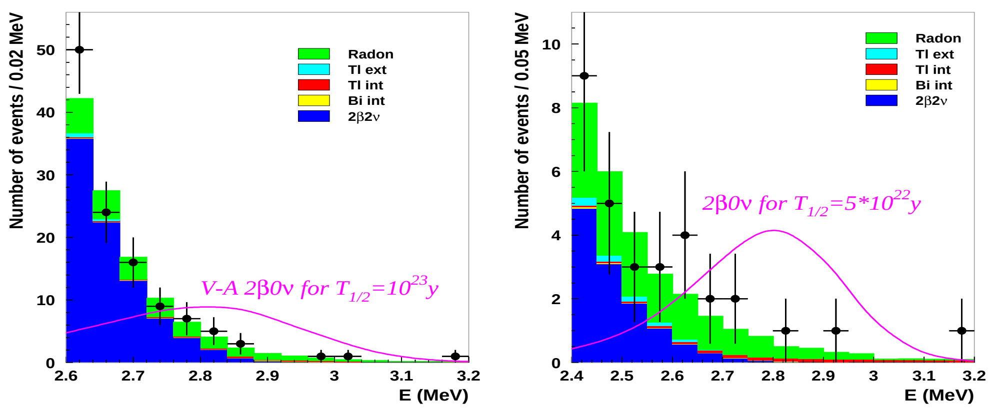

Figure 3: Distribution of the energy sum of two electrons for ^{100}Mo (left) and ^{82}Se (right).

4 Summary

The NEMO 3 experiment continues taking data to search for neutrinoless double beta decay with the target sensitivities $\sim 2 \cdot 10^{24}$ y for ^{100}Mo and $\sim 8 \cdot 10^{23}$ y for ^{82}Se in terms of 90% C.L. limit on $T^{0\nu}_{1/2}$. No evidence for a signal was observed after 693 days of effective data collection. The 90% C.L. limits were obtained: $T^{0\nu}_{1/2}(^{100}Mo) > 5.8 \cdot 10^{23} y$ and $T^{0\nu}_{1/2}(^{82}Se) > 2.1 \cdot 10^{23} y$.

The half-lives of $2\nu\beta\beta$-decay of ^{100}Mo, ^{82}Se, ^{116}Cd, ^{130}Te, ^{150}Nd, ^{96}Zr and ^{48}Ca were measured in NEMO 3. New preliminary results were obtained for two of these isotopes: $T^{2\nu}_{1/2}(^{96}Zr) = [2.3 \pm 0.2(stat) \pm 0.3(syst)] \cdot 10^{19} y$, $T^{2\nu}_{1/2}(^{48}Ca) = [4.4^{+0.5}_{-0.4}(stat) \pm 0.4(syst)] \cdot 10^{19} y$.

References

1. R. Arnold *et al*, *Nucl. Instrum. Methods* A **536**, 79 (2005).
2. R. Arnold *et al*, *Phys. Rev. Lett.* **95**, 182302 (2005).
3. T. Junk, *Nucl. Instrum. Methods* A **434**, 435 (1999).
4. M. Kortelainen and J. Suhonen, *Phys. Rev.* C **76**, 024315 (2007).
5. F. Šimkovic *et al*, *Phys. Rev.* C **77**, 045503 (2008).
6. E. Caurier *et al*, *Phys. Rev. Lett.* **100**, 052503 (2008).